Our Motivation:

to work for a better future

Climate change is one of the greatest challenges of our time. In order to still reach the 1.5° target, all scientists must join forces and ask themselves how they can make a contribution with their research.

That is what we have done. In order to slow down climate change, carbon capturing and storage methods (CCS) will gain in importance in the future. CCS refers to the storage of CO2 in the seabed so that it does not reach the atmosphere. An other point is, that renewable energies require large quantities of rare metals. To meet this demand, deep-sea mining, the extraction of these metals from the seabed, has recently become a topic of discussion.

In order to realise these two projects, meaningful models of the seabed are important, but subsurface modelling is an NP hard problem. Quantum computers could help to improve these calculations.

State of the art

Subsurface imaging is done via inverse analysis of the hydraulic head to calculate the permibility of the aquifer.

Current methods to optimize subsurface imaging:

- Nature inspired global solvers [Pierini et al., 2019]
  - Firefly Algorithm
  - Whale Swarm Optimisation
- Simulated Annealing [Rothman, 1985]

Other methods in research:

- Quantum Annealing

Our idea

Starting from the quantum annealing approach, we want to implement a quantum gate-based subsuface imaging algorithm in Qiskit.

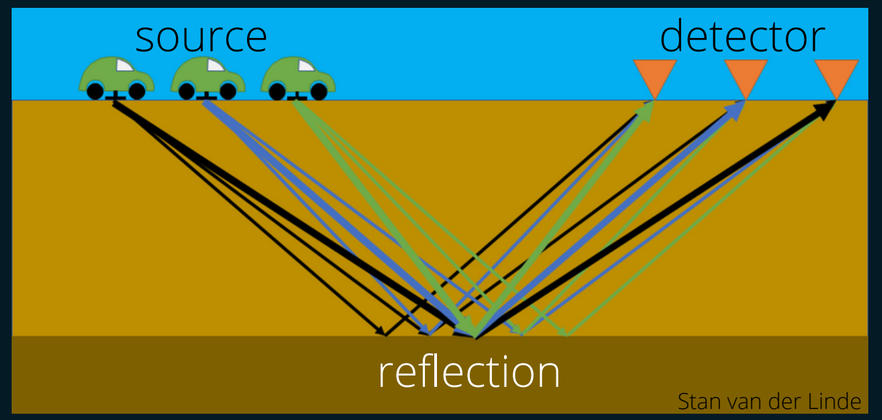
Why Quantum Computing?

For seismic experiments, multi-path analysis is required as shown in the picture on the right. The problem size is given by:

$$Traces^{possible\ shifts} \rightarrow \text{NP hard problem}$$

Quantum computers are expected to overcome the size limitation of classical computers in the future, because of their different computational approach.

At the moment, gate-based quantum computers are composed of O(10) bits while quantum annealers have $O(10^3)$ bits. Despite that, gate-based quantum computers are more universal than annealers. Together with the rapid development of technology, gate-based quantum computers will most likely dominate the market in the future and gate-based quantum algorithms will be needed.



What we have done

We were able to implement a code similar to the quantum annealing approach using Qiskit.

Looking into existing algorithms

After comparing existing algorithms and their weaknesses, we focused on the paper "An approach to quantum-computational hydrologic inverse analysis" by Daniel O'Malley [2018]. Our goal was to implement a quantum gate-based solution similar to the approach described in the paper.

Research

We found an already existing Quadratic Optimization function in Qiskit, which we decided to use. Additionally, we looked into SymPy to describe some of our mathematical functions.

Qiskit Implementation

We implemented the three examples from the paper in Qiskit: the small 1D problem, a large 1D problem and a 2D problem.
For this analysis we used self-generated data sets.
In a last step, we added an error analysis routine for the 1D problem.

Next Steps

The existing code is a solid starting point and lays a good foundation for further development of the project. Nevertheless, the success of the project depends to a large extent on the further development of quantum computers. This page outlines our strategy for continuing the work on subsurface imaging using a quantum gate appraoch.

Test on real data

In a next step, our program should be tested on real geophysical data. The model achieved with our code must be compared to classical models and models achieved by Quantum Annealing.

Iterative circle

By benchmarking our algorithm against the reality and other existing models, we can iterativly improve and verify our results.

Waiting for Quantum Computers to scale

To perform better than the existing solutions, it is necessary that quantum computers will scale up. Once this happens, we are ready to revolutionize subsurface-imaging.